Natural modes of swimming: new swimming styles, how to swim with efficient buoyant velocity

Lepota L. Cosmo

lepota.cosmo@hotmail.com

Abstract

Swimming hydrodinamics have significiantly applied BCF to techniques. In addition research on undulatory motion, undulatory BCF anguilliform, and undulatroy MPF could give interesting conclusions. These natural modes are seen as alternative to BCF techniques introducing some missing elements as buoyancy, gliding and floating to complement the scale of man's hydrodynamics. Study draws conclusion from hydrodynamic properties of caphalodops as implied to human kinetics, discerning significant patterns, as floating, puddle, undulation or swim efficiency. In biomechanical aspect meduzoi and aguilliform shows positive results: low Reynolds number, low viscous forces, stability, great luminar flow, linear momentum and efficient velocity.

KEY WORDS: anguilliform, undulation, buounacy, swimming technique

INTRODUCTION

Regarding development of style and techniques, the major emphasis was put on speed sports techniques involving oscillation and BCF movement as the basis of its dynamics. Swimming was largely modified by pursue for these oscillatory seeking on improvements on vertical velocity.

Significant progress has been made in efficiency and analysis of human hydrodynamics. However, general paradigm used pattern of fish-like swimming, especially those of thuniform manner trying to take conclusions on elements of human adaptable dynamics. Buoyancy is primarily understood in function of velocity, and not as an independent variable. Secondly, the need for swimming efficiency arose within coatching as convenience. Some would see necessity of taking into account all swimming variables and motions through out of a full scale of natural hydrodynamics. The history of swimming styles was very abundant one. The Frenchman Melchisédech Thévenot wrote The Art of Swimming, describing a breaststroke very similar to the modern breaststroke. While the British raced using breaststroke, the Native Americans swam a variant of the front crawl further developed into Trudgen style. The inefficiency of the trudgen kick led Australian Richard Cavill to try new methods. He used the Australian crawl stroke in 1902 at the International Championships and set a new world record. In 1934 David Armbruster, coach at the University of Iowa, devised a double overarm recovery out of the water. This "butterfly" arm action gave more speed but required greater training and conditioning. In 1837, London's six artificial pools hosted competitions. They began to formulate new swimming styles including the sidestroke and later evolved freestyle swimming. The 1896 Athens Olympic Games included swimming, offering the 100 meter and 1500 meter freestyle. The backstroke was eventually perfected by Australian swimmers, who bent their arms underwater to increase the horizontal, forward push. While the backstroke had always included a straight arm during the underwater push, from 1935 to 1945, this new technique became a swimming style that is now practiced all over the world.

METHODS

Swimming style - eel

The modern swimming styles encompass artificial propulsion dynamics on-surface, concerning less with natural modes, and widespread underwater swimming techniques. Natural modes are however the only known mode of swimming having its due to density dynamics, efficient and more adjustable swimming solution. Indeed, underwater technique is inclusive example of hydrodynamics with different forms of locomotion within the water providing various velocity.

Natural swimming motions are divided into: anguilliform, subcarangiform, carangiform, thuniform, ostraciiform, similar as in Lindsey (1978). Anguilliform in correlation with dynamics of eel, lamprey and sea snake adjusted to morphology and hydrodynamics of man. Much is done in research on anguilliform body dynamics Bottle (1971), anguilliform with fin locomotion Smith (49), and undulating modeling Long (2002).

Lighthill (1970) view eel style as aquatic propulsion of high hydromechanical efficiency. On Saragosso theory eel style is generally proved to be technique with low energy cost.

Characteristics of eel swimming style: small frictional drag, low aerobic demand, active buoyant force, good gliding, undulatory propulsion, high frequencies and low swim velocity.

Undulation on surface reduce to half body friction creating active figure buoyancy.

Friction is the main property of this style, additional forces applied on friction are undulation and glide.

Surface motion will try to assimilate underwater style of eel (Figure 1.). Start position of swimmer is backward, hands to body and legs close floating. Swimmer then starts to undulate
first with hand and shoulders then trespassing undulation on legs. The propulsion force is mainly generated by hands, which stay all the time close to body. Swimmer tries to relay

on gliding flow of water moving easily and swiftly. Legs do not perform flutter stroke as it will create force opposite to undulatory. Efficiency is achieved by undulating along the whole body, intermittently and at intervals. Once the body is introduced in undulation, it will soon achieved optimal velocity. The purpose of transfer from preparation to propulsion phase is to generate gliding flow, which swimmer will use as additional lift in moving forward and up.

Swimmers in nature use body undulations to generate these propulsive and maneuvering forces. The anguilliform kinematics is driven by muscular actions all along the body.Proposed natural modes of swimming have floating as basic force in relation with neutral buoyancy of underwater swimmers.

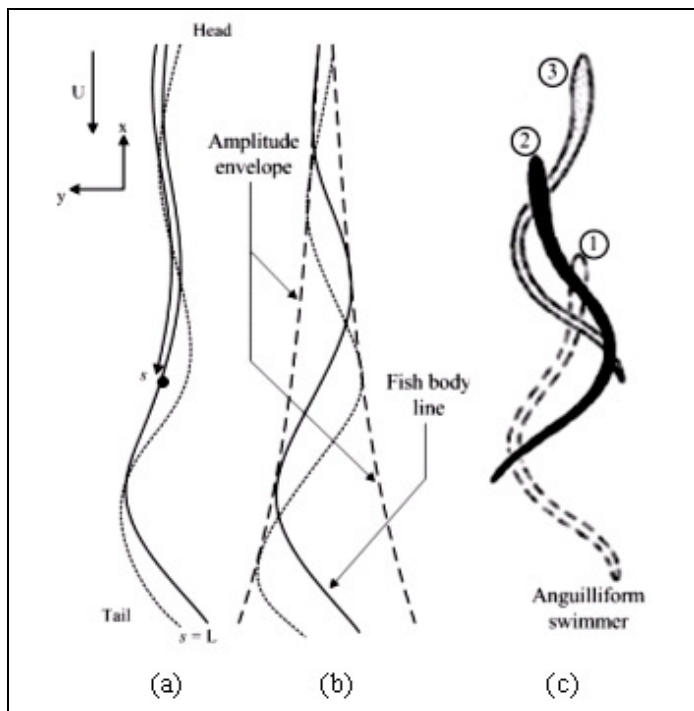In backward technique floating is the constant force, to which additional dynamics are applied.

Figure 1. Coordinate systems for elongated body modeling
of eel (Willy,_).

Smaller amount of energy is required, the smaller static and dynamic momentum, which make technique energy efficient. Natural techniques are based on maximum propelling efficiency, use of buoyancy and different gliding postures. In fact by (Costello, 2008), in other conditions being equal those athletes that float more, have a lower surface friction to water. The aquatic environment imposes particular organic and

functional adaptations, athlete works horizontally and carries out the propulsive action mainly (70%) to completely (endurance swimmers) by using arms.

Viscosity is one more factor to count with. Undulation style uses biodynamics of water snake implying adhesive forces, surface pressure and water thrust. There is subsequently less wavy trail, making propulsive frothy water turbulence.

Concerning human morphology oscillatory flatter kick is more suitable, hence all swimming techniques exert vertical oscillation with upward propelling. Therewithal, it would be interesting to introduce horizontal undulation to swimming technique. Flicker kick, as vibration of both, hands and legs, with slight deviation of arms within regular undulation will produce powerful horizontal dynamics. Swimmer by propelling is not just vibrating, this is proved to be insufficient, but rather producing undulating waves.

Natural movements of swimmer follow the movement of eel. The difference is the swimmers orientation. It is more backward than forward. Swimmer front correspondent to eel's front.

The initial move is made by shoulders gliding backward and curve. Meandering is transmitted to the hips and legs. Undulation is most pronounced between the shoulders and thighs. At the end of swimming cycle, legs produce flicker kick as collateral to undulatory movement.

Similarly, cholchis stroke is the style with along body movements, most closely resembling the biodynamics of this undulation style. However, differences can be seen in additional factors: floating, friction, fidgeting. Giving the small friction, eel style is very useful in moderate to fast underwater currents, and in combination with other backstroke techniques as well as with some floating styles.

Swimming style - octopus

Swimmer starts from floating posture backward spreading his arms and feet in the star position, arms raised further up to the maximum momentum, all the time keeping them parallel to the surface, then in the propulsive phase returning the same way, putting his hands to the body and legs merging.The hands and legs are all the time on to the surface and do not leave the horizontal plane but moving left and right. Legs opening to the 45 degree returning then returning and closing. Arms smoothly from 90, 120 degrees of leg axis, then cling to the legs.

More economical means of motion involves alternative movements of leg and arms, first arms then legs (Dalton, 1918). Effective swimming, however, impliestheir parallel movement. Breathing in octopus backstroke is easier than in other strokes, as the mouth and nose are always over water. The least use of the energy of swimmer, relying fully on water thrust, then floating, gliding, and pause.

Octopus is a swimming technique that involves minimal consumption of swimmer kinetic energy. Jellyfish use force of action and reaction, as a widespread form of movement. According to Bartol (2012) in contrast to fishes, squids and many jellyfishes do not rely on undulatory mechanisms over their entire range of life history stages. Jellyfish, such as Aurelia aurita (see Figure 2.), are capable of generating thrust by both paddle and jet mechanisms but rely primarily on jetting throughout ontogeny with only negligible thrust generation by paddling of the bell margin (McHenry, 2003), although some jellyfish lineages do rely heavily on rowing propulsion throughout development (see Costello et al., 1981). At juvenile and adult life stages, squid rely more heavily on undulatory/oscillatory fin activity during low and intermediate speed propulsion to complement their pulsed jet (Anderson and DeMont, 2000; Bartol et al., 1999; Hoar et al., 1994; O'Dor, 1974).

For our study most useful will be observation of Ephyra hydrodynamics, paddle mechanism of juvenile hydromedusa with its implications on human velocity. Conclusion drawn out from are completely new swimming technique.
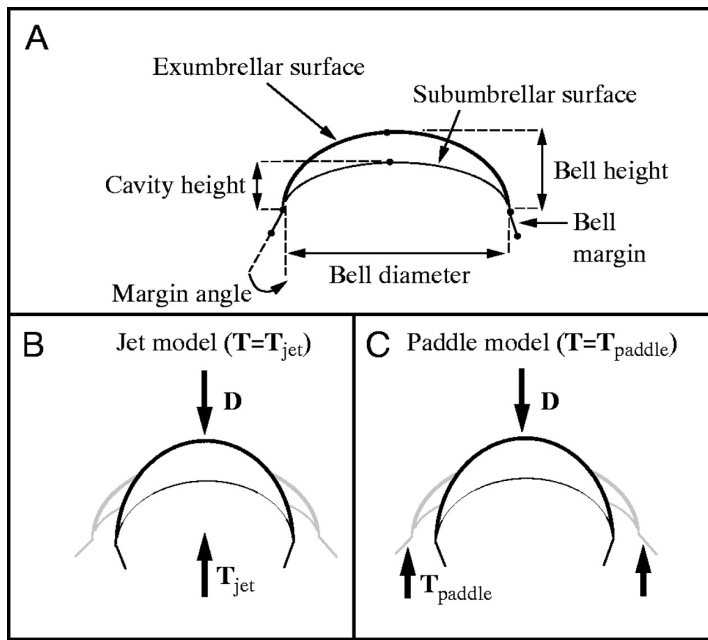
Figure 2. Morphometrics and hydrodynamic modeling (B,C) The two hydrodynamic models used in the present study are illustrated with the drag, **D**, and thrust, **T**, vectors predicted to be generated as the bell contracts and the bell margin adducts. (B) The jet model assumes thrust to be generated by a jet, $\mathbf{T}_{jet}$. (C) The paddle model assumes thrust is generated by paddling, $\mathbf{T}_{paddle}$. (34)

Of all the components of the fluid forces acting on the swimmer's body, the buoyant force is probably the largest and most influential on the horizontal alignment of the swimmer.

Floating styles involve buoyancy as one of the most important factors. (Rushall, 1930) has done important study on floatation in swimming, (Gagnon et al., 1981) on buoyancy, technologic to the measurement of the center of volume (Hay, 1993), (McLean and Hinrichs, 1975) factors affecting buoyancy and performance in swimming.

Referring to conducted research woman swimmers should have more predispositions in floating techniques. This is influenced by factors of higher buoyancy center, specific body structure and VO2max.

Costello and associates (2008) concluded that due to lower friction to water, women are advantaged, having a body structure richer in fat which is distributed especially inlower limbs, and this favors movement in water. This advantage expresses itself in the lower energy cost of swimming in women than

in men. Klentrou and colleagues (1992) compared the oxygen demand of back crawl in male and female competitive swimmers and to examine the effect of stroke mechanics on these costs and results indicate that submaximal VO2 in back crawl swimming does not increase in proportion to body mass.

Floating styles are the best solution for long distance swimming, in combination with crawl backstroke techniques (see Blache, 1918). This styles provide efficiency (commonly defined as the rate of useful energy expenditure divided by the total rate of energy consumption) that is a crucial parameter for swimmers over long distances.

Schleihauf (1979) investigated lift and drag forces on hand models in an open-water channel at certain steady-state flow conditions. His experiments showed a specific relationship between drag and lift coefficients and the attack angle. The Schleihauf experiments were replicated by (Berger, 1995) and she stated in her conclusions: a) It has been shown from a theoretical point of view that propulsive forces during human swimming can be more efficiently derived from lift forces then from drag forces. At high lift forces the loss of energy will be minimal. Consequently, a proper technique should generate as much lift as possible.

Styles with great buoyancy can generate high-propulsive lifts. A swimmer who tends to sink in the static position by Wilson et al. (2008) receives an increased drag force when swimming and has to increase the kicking effort necessary to elevate the legs to maintain the whole body horizontal alignment. Consequently, a greater amount of energy is required to overcome the increased drag and to maintain strong kicks to keep the horizontal alignment of the body.

Substantial energy savings are likely achieved in natural locomotion by allowing a mix of actively controlled and passively responsive deformation.

Alves and colleagues (1998) were focusing on swimming velocity; Toussaint (48) says referring triatlets in his research that the results suggest that on average the better swimmer distinguish themself from by a greater distance per stroke rather then a higher stroke frequency.

RESULTS

Breder (1926) discerns subsequent swimming modes of fishes associated with BCF and BPF motion, undulatory to oscillatory, anguilliform, carangiform, thuniform, ostraciiform. Swimming hydrodynamics have significantly applied BCF to techniques. In addition research on undulatory motion, undulatory BCF anguilliform, and undulatroy MPF could give interesting conclusions.

In biomechanical aspect anquilliform shows positive results: low Reynolds number, low viscous forces, stability, great laminar flow, linear momentum, efficient velocity.

Eels style features long, anterior cylindrical, posterior compressed body motion typical to slender-body theory, shoulder twist, partial encounter to total underwater friction, flexibility, vorticity.

For negatively buoyant swimmers, hydrodynamic lift must be generated to supplement buoyancy and balance the vertical forces, there is necessarily need to actively exert high vertical forces because the effect of buoyancy can counter the downward pull of gravity ensuring that swimmer do not sink in initial phase. Dv/du would suggest that technique should have positive velocity rate at the very start, adding active force of swimming in continuation. Modern swimming theoretical research should encompass the complete scale of buoyant techniques.

Just as shown: C*=dv/du, buoyant swimming velocity can be increased at low viscosity levels, likewise velocity is partial due to the floating. Not only in static floating posture, when velocity is very small and viscosity high, but in propel phase as well, increment hydrodynamics of gliding perform high csm numbers. Studies have been made on Lolliguncula brevis, Potamotrygon orbignyi, large-finned deep-sea squids, Sepia Officinalis Belonidae, providing respective hydrodynamic insight. Some works have been done on Anguillae and Molusca swimming technique.

Interesting observation could be made on Hemiptera technique, as comparable to buoyant style. Highly flexible ribbon shaped bodies with wide span are found among many species: Chimaeri-dae, Notacanthiformes, Regalicidae, Cepolidae, Trichiruidae, Siluriformes, Trachypteridae.

Hydrodinamically octopus style uses to great extend surface pressure, as discern in preparation phase, providing maximum body surface, with delayed stall and small frictional drag.

DISCUSSION

Octopus technique could be significantly modified to subsequent sepia bone style producing motion by more specific gliding.

Swimmer is floating having his hands open and legs joint, straight and parallel to the surface.

In this style, propulsion is generated by hands, while legs are in counterbalance. Hands are moving continuously in full radius from above the head to the thigh, exerting backward glide.

In this system it is already possible to perform forward backstroke as innovative swim. Arms are not moving downward but upward in initial stroke, so that the swimmer is pushed forward, as in front crawl. Swimmer's trunk imitates the form of sepia bone by gliding, moving forward or backward.

The balance is very important as in Vecchione et al. (2008), neutral buoyancy of cepahalops in Wilbur et al. (1995), and the buoyancy of the Sepia Officinalis Denton and Gilpin-Brown (1961). Swimming technique postulates floating as an analogy to molecules neutral buoyancy. It is great element which offsets the force

of gravity that would otherwise cause the object to sink. In fact most cephalopods are about 2-3% denser than seawater, and cephalopods float.

In (Denton and Gillip-Brown, 1961) the excess weight in sea water of the living tissues of Sepia officinalis (L.) is approximately balanced by the cuttlebone, which accounts for about 9•3% of the animal's volume. The density of cuttlebone varies around 0•6.

Further rajiform, on example of Taeniura lymma, could arise from stylization of jellyfish technique, the same paths, and the hands that produce movements similar to wingstroke.

Study draws conclusion from hydrodynamic properties of caphalodops as implied to human kinetics, discerning significant patterns, as floating, puddle, undulation or swim efficiency.

Sepia bone could be effective as drifting technique, in steering and floating in the fast flow, using only hand to navigate the stream, complementary as passive to more proactive swimming techniques.

The most intriguing is forward backstroke which could be seen as improvement of sepia bone style.

Cuttlefish style stroke active use of arm and legs, in full swing and in radius similar to "octopus". Anew, triple pattern could be discern, with initially legs close, arms to the legs. Legs go 30 degree under water, with the swimmer, then up to the suface straightly, arm movements, bend at the elbows, with the dive.

These natural modes are seen as alternative to BCF techniques introducing some missing elements as buoyancy, gliding and floating to complement the scale of man's hydrodynamics.

Natural modes and extravagant swimming is applicable to human motion not only the oscillatory paradigms.

CONCLUSIONS

Various swimming modes and styles could be recognized in underwater dynamics and in sustainable swimming. Primarily anguilliform, rajiform, molluscas and buoyant techniques, amphibious sustainable strokes. Very interesting is the technique of human klokan style. Undulatory motion give much to consideration on possibility of efficient human hydrodynamics. Buoyant styles provide such useful conclusions. Researcher would see in future necessity of taking into account all swimming variables and motions throughout out of a full scale of natural hydrodynamics.

REFRENCES

1. Anderson, E. and M. Demont. (2000). "The mechanics of locomotion in the squid Loligo pealei: Locomotory function and unsteady hydrodynamics of the jet and intramantle pressure". *The Journal of experimental biology*, 203 (Pt 18), 2851–2863.

2. Anderson, E. J. and M. E. DeMont. (2005). The locomotory function of the fins in the squid Loligo pealei. *Marine and Freshwater Behaviour and Physiology*, 38, 169 -189.

3. Alves, F., M. Costa, J. Gomes-Pereira. (1998). The influence of swimming velocity on the kinematic characteristics of backstroke swimming. In: Riehle H, Vieten M (eds). Proceedings II of the XVIth International Symposium on Biomechanics in Sports. Konstanz: Universitätsverlag Konstanz, 104–107.

4. Arellano, R. (1999). Vortices and propulsion. Applied Proceedings of the XVII International Symposium on Biomechanics in Sports: Swimming, 53 – 65.

5. Bartol, I. K., P. S. Krueger, W. J. Stewart,and J. T.Thompson. (2012). Hydrodynamics of pulsed jetting in juvenile and adult brief squid *Lolliguncula brevis*: evidence of multiple jet `modes' and their implications for propulsive efficiency. *The Journal of Experimental Biology*, 1889-1903.

6. Blevins, E. L., V. George and G. V. Lauder. (2012). Rajiform locomotion: three-dimensional kinematics of the pectoral fin surface during swimming in the freshwater stingray Potamotrygon orbignyi. *The Journal of Experimental Biology*, 215, 3231-3241

7. Blache, P. (1908). *Traité pratique de natation et de sauvetage*, Paris : Garnier

8. Bowtell, G, T. L. Williams. (1991). Anguilliform body dynamics - Modeling the interaction between muscle activation and body curvature. *Philosophical Transactions of Royal Society London B*, 334, 385-90.

9. Breder, C. M. (1926). *The locomotion of fishes*. Zoologica, 4, 159–256.

10. Castro-Santos, Th. (2005). Optimal swim speeds for traversing velocity barriers: an analysis of volitional high-speed swimming behavior of migratory fishes. *The Journal of Experimental Biology,* 208, 421-432.

11. Chatard, J.C., J.M. Lavoie, B. Bourgoin, J.R. Lacour. (1990). The contribution of passive drag as a determinant of swimming performance. *International Journal of Sports Medicine*, 11, 367-372.

12. Christianson, R. A., G. Weltman, G. H. Egstrom. (1965). Thrust Forces in Underwater Swimming, Human Factors. *The Journal of the Human Factors and Ergonomics Society*, 7(6), 561-568.

13. Colin, S. P. and J. H. Costello. (2002). Morphology, swimming per formance and propulsive mode of six co-occuring hydromedusae, *The Journal of Experimental Biology*, 205, 427–437

14. Clarys, J.P. (1979). Human morphology and hydrodynamics. In: Terauds J, Bedingfield EW (eds) Swimming III. University Park Press, Baltimore, 3–44.

15. Costello, J. H., S. P. Colin and J. O. Dabiri. (2008). Medusan morphospace: phylogenetic constraints, biomechanical solutions, and ecological consequences. *Invertebrate Biology*,127, 265 -290

16. Dalton, F. E. (1918). *Swimming scientifically taught*, Funk and Wagnalls Company, New York and London

17. Dal Monte, A., G. Mirri and F. F. Sardellla. (1997). Frontiers of Ergometry and Hydrodynamics in Aquatic Sports. *Kinesiology*, 2(1), 69-74.

18. Daniel, Th. (1983) L. Mechanics and energetics of medusan jet propulsion. *Canadian Journal of Zoology*, 61(6), 1406-1420.

19. Denton, E. J. and J. B. Gilpin-Brown. (1961). The Buoyancy of the Cuttlefish, *Sepia Officinalis* (L.). *Journal of the Marine Biological Association of the United Kingdom*, 41(2), 319-342.

20. Gagnon, M., R. Montpetit. (1981) Technological development for the measurement of the center of volume in the human body. *Journal of Biomechanics*, 14, 235-241.

21. Gray, J. *(*1933). Studies in animal locomotion. I. The movement of fish with special reference to the eel. *The Journal of Experimental Biology*, 10, 88 -104.

22. Graig, A. B. Jr. and D. R. Pendergast. (1979). Relationships of stroke rate distance per stroke and velocity in competitive swimming. *Medicine and science in sport*, 11(3), 278-283

23. Hay, J.G. (1993). *The Biomechanics of Sports Techniques*, 4th ed.Prentice-Hall, Englewood Clifs, NJ

24. Hoar, J. A., E.Sim, D. M. Webber and R. K O'Dor. (1994). The role of fins in the competition between squid and fish. In Mechanics and Physiology of Animal Swimming (ed. L. Maddock, Q. Bone and J. M. C. Rayner), pp. *27* -33. Cambridge: Cambridge University Press

25. Holmer, I. (1974). Propulsive efficiency of breaststroke and free style swimming. *Europian Journal of Applied Physiology*, 33, 95-103 .

26. Lauder, G. V., E. G. Drucker, Forces. (2002). Fishes, and Fluids: Hydrodynamic Mechanisms of Aquatic Locomotion. *Physiology,* 17(6), 35-240.

27. Liao, J. (2002). Swimming in needlefish (Belonidae): anguilliform locomotion with fins. *The Journal of Experimental Biology*, 205, 2875-2884.

28. Liao, J. C. (2007). A review of fish swimming mechanics and behaviour in altered. *Philosophical Transactions of Royal Society B*, 362 (148), 1973-1993.

29. Lighthill, M. J. (1970). Aquatic animal propulsion of high hydromechanical efficiency. *Journal of Fluid Mechanics*, 44, 265-301.

30. Lighthill, M. J. (1971). Large-amplitude elongated-body theory of fish locomotion. *Proceedings of Royal Society London A*, 179, 125-138.

31. Lindsey, C. C. (1978) Form, function and locomotory habits in fish, in *Fish Physiology* VII Locomotion , W. S. Hoar and D. J. Randall, Eds. New York: Academic, 1–100

32. Long, J. H., R. G. Root and P. Watts. (2002). Is an undulating fish an oscillating wing?. *Intergrative and Comparative Biology*, 42:1268.Karpovich, P.V. (1933). Water resistance in swimming. *Research Quarterly*, 4, 21–28

33. Klentrou, P.P., R.R. Montpetit. (1992). Energetics of backstroke swimming in males and females. *Medicine and Science in Sports and Exercise*, 24(3), 371-5.

34. Kochin, N.E., I.A. Kibel, and N.V. Roze. (1964). Theoretical Hydromechanics. Wiley, New York

35. McHenry, M. J., J. Jed. (2003). The ontogenetic scaling of hydrodynamics and swimming performance in jellyfish (Aurelia aurita). *The Journal of Experimental Biology*, 206 (Pt 22), 4125-37.

36. McLean, S.P., R. Hinrichs. (1995). Factors affecting buoyancy and performance in competitive swimming. *Medicine and Science in Sports and Exercise (suppl.)*, 27, 1298.

37. Miller, D. J. (1975). Biomechanics in swimming. Exercise and sport science reviews. Academic Press, Inc.

38. Montpetit R., H. Smith, G. Boie. (1988b). Swimming Economy: How to standardize the data to compare swimming proficiency. *Journal of Swimming Research*, 4, 5–8.

39. O'Dor, R. K. (1988). The forces acting on swimming squid. The *Journal of Experimental Biology*, 137, 421– 442

40. Prampero, P.E. di, D. R. Pendergast, D. W. Wilson, D. W. Renie. (1974). Energetics of swimming in man. *Journal of Applied Physiology*, 37, 1-4.

41. Rosenblum, H. G., Jr. J. H. Long, and M. E. Porte. (2011). Sink and swim: kinematic evidence for lifting-body mechanisms in negatively buoyant electric rays Narcine brasiliensis, *The Journal of Experimental Biology*, 214, 2935-2948.

42. Rushall, B. S. (2007). Flotation in swimming:The forgoten technique modifier. *Swimming science bulletin,* 36.

43. Russell, F. S., G. A. Steven. (1930). The Swimming of Cuttlefish. *Nature*, 125 (3163), 893

44. Schleihaft, R. A. A. (1979). A hydrodynamic analys of swimming propulsion. In: *Swimming III*, J. Terauds and J. E. Bedingfield (Eds.) Baltimore: University park press, 70-109.

45. Shirgaonkar, A. A, O. M. Curet, N. A. Patankar, and M. A. MacIver. (2008). The hydrodynamics of ribbon-fin propulsion during impulsive motion. *The Journal of Experimental Biology*, 211, 3490-3503.

46. Smith, H. K., R. R. Montpetit, H. Perrault. (1988). The aerobic demand of backstroke swimming, and its relation to body size, stroke technique, and performance. *European Journal of Applied Physiology and Occupational Physiology*

47. Smith, D. G. and K. A. Tighe, (2002). Freshwater eels. Family Anguillidae. In Fishes of the Gulf of Maine (ed. B. B. Collette and G. Klein-MacPhee). Washington: Smithsonian Institution Press, 92-95.

48. Taylor, G. (1952). Analysis of the swimming of long narrow animals. *Proceedings of Royal Society of London A*, 211, 158-183.

49. Toussaint, H. M. (1990). Diffrences in proplelling efficiency between competitive and triathlon swimmers. *Medicine and science in sport and exercise*, 22 (3), 409-415.

50. Triantafyllou, M. S., Triantafyllou, G. S. and Yue, D. K. P. (2000). Hydrodynamics of fishlike swimming, *Annual Review of Fluid Mechanics*, 32, 33-53.

51. Tytell E. D. , G. V. Lauder. (2004). The hydrodynamics of eel swimming. I. Wake structure*, The Journal of Experimental Biology,* 207, 1825-41.

52. van Ginneken, V.E., Antonissen, U.K. Muller, R. Booms, E. Eding, J. Verreth, G. van den Thillart. (2005). Eel migration to the Sargasso: Remarkably high swimming efficiency and low energy costs. *The Journal Experimental Biology,* 208, 1329-35.

53. Vecchione, M., R. E. Young, A. Guerra, D. J. Lindsay, D. A. Clague, J. M Bernhard, W. W Sager, A. F Gonzalez, F. J. Rocha, and M. Segonzac. (2001). Worldwide observations of remarkable deep-sea squids. *Science,* 294, 2505-2506.

54. Vecchione, M., C. F. E. Roper, E. A. Widder, and T. M. Frank. (2002). In situ observations on three species of large-finned deep-sea squids. *Bulletin of Marine Science,* 71, 893-901.

55. Wakayoshi, K. , L. J. D'Acquisto, J. M. Cappaert, J. P. Troup. (1996). Troup Relationship Between Oxygen Uptake, Stroke Rate and Swimming Velocity in Competitive Swimming. International Journal of Sports Medicine, 16(1), 19-23.

56. Weihs, D. and P.W. Webb. (1983). Optimization of locomotion. Fish Biomechanics (eds P. W.Webb & D.Weihs), pp. 339–371. Praeger, New York

57. Wilbur, Karl M, M.R. Clarke, E.R.Trueman, eds. (1985), "11: Evolution of Buoyancy and Locomotion in recent cephalopods". The Mollusca, 12. Paleontology and neontology of Cephalopods. New York: Academic Press

58. Willy, A., Coordinate systems for elongated body modeling of eel, Scholl of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore

59. Wilson, M., J. Eldredge. (2008). Passive mechanics in jellyfish-like locomotion. Bulletin of the American Physical Society. 61st Annual Meeting of the APS Division of Fluid Dynamics , 53 (15)